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# Fermilab Short Baseline Neutrino Program

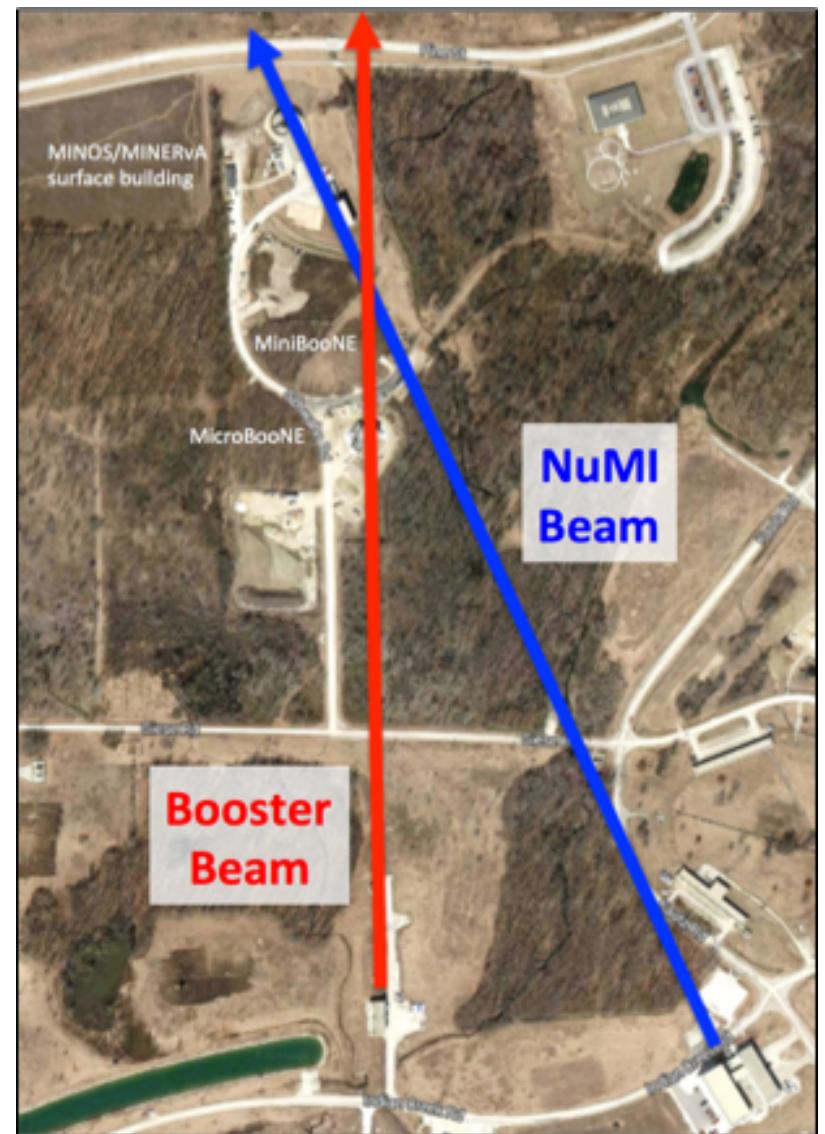
Peter Wilson

Workshop on Intermediate Neutrino Program

4 February 2015

# Booster Short Baseline Neutrino Beam

- Short-baseline experiments at Fermilab built on well established existing Fermilab Booster Neutrino Beamlne (BNB)
  - 8 GeV proton beam,  $\nu$  flux peaks ~700 MeV
  - Robust target and horn system
  - BNB neutrino fluxes well understood due to dedicated hadron production data (HARP experiment @ CERN) and 10+ years of study by MiniBooNE and SciBooNE
  - Beam near surface (~10m) => modest civil construction cost



# Brief History of Fermilab SBN Program

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- Second generation of BNB based experiments about to start:
  - MiniBooNE: 2003-2013(?) (see Mark Thomson's talk)
  - SciBooNE: 2007-2008
  - MicroBooNE: follow-up on MiniBooNE anomalies, start data-taking in 2015
- Proposals to address short-baseline anomalies using multiple LAr detectors under consideration for several years (e.g. ICARUS@CERN, LAr1@FNAL)
- At January 2014 Fermilab PAC two new proposals for next phase at BNB:
  - **P-1052: ICARUS@FNAL:** Updated ICARUS-T600 detector plus new T150 as near detector on the BNB for oscillation searches.
  - **P-1053: LAr1-ND:** LAr1-ND + MicroBooNE (possibly followed by 1kton scale far detector).
- Soon after, proponents of **ICARUS**, **LAr1-ND**, and **MicroBooNE**, along with representatives from **FNAL**, **INFN** and **CERN**, started working together to develop a plan for a coherent SBN physics program.

## P5 Recommendations

**Recommendation 12:** In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.



May, 2014

**Recommendation 15:** Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.

# The Three Neutrino Paradigm

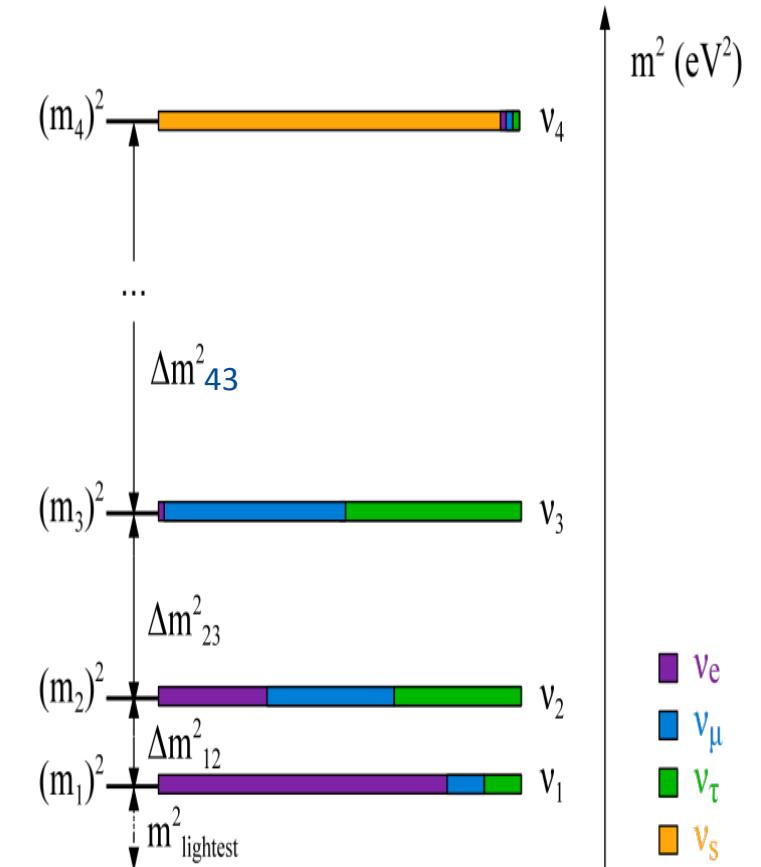
- Results from multiple experiments have hinted at a possible additional oscillation
- While each of the measurements alone lack the significance to claim a discovery, together they could be hinting at important new physics

Experiment	Type	Channel	Significance
LSND	DAR	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ CC	$3.8\sigma$
MiniBooNE	SBL accelerator	$\nu_\mu \rightarrow \nu_e$ CC	$3.4\sigma$
MiniBooNE	SBL accelerator	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ CC	$2.8\sigma$
GALLEX/SAGE	Source - e capture	$\nu_e$ disappearance	$2.8\sigma$
Reactors	Beta-decay	$\bar{\nu}_e$ disappearance	$3.0\sigma$

K. N. Abazajian et al. "Light Sterile Neutrinos: A Whitepaper", arXiv:1204.5379 [hep-ph], (2012)

One thing is certain...

**The discovery of a light sterile neutrino would be monumental for particle physics and cosmology**



# The SBN Proposal

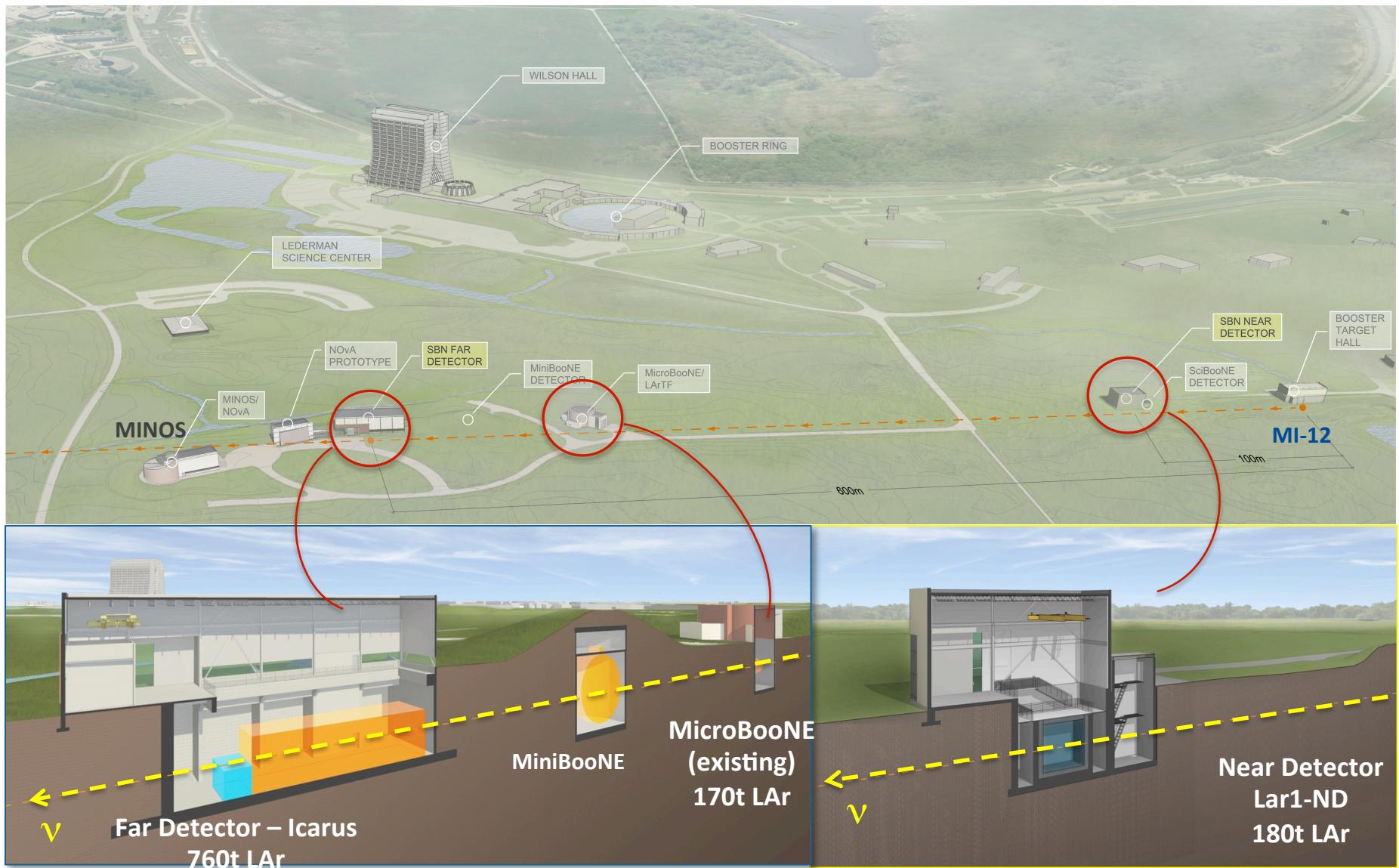
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- Returned to the January 2015 PAC meeting with an updated proposal:

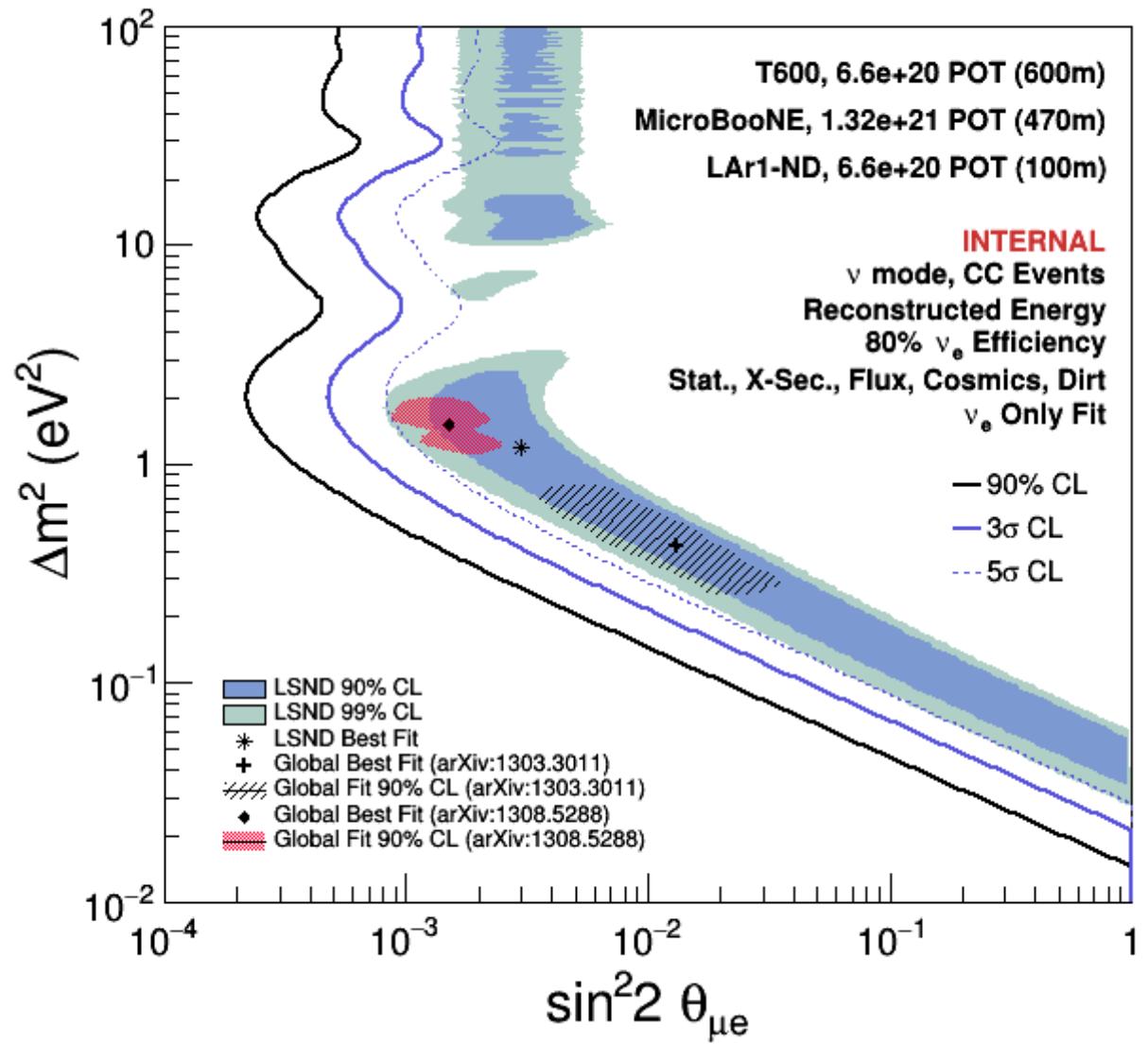
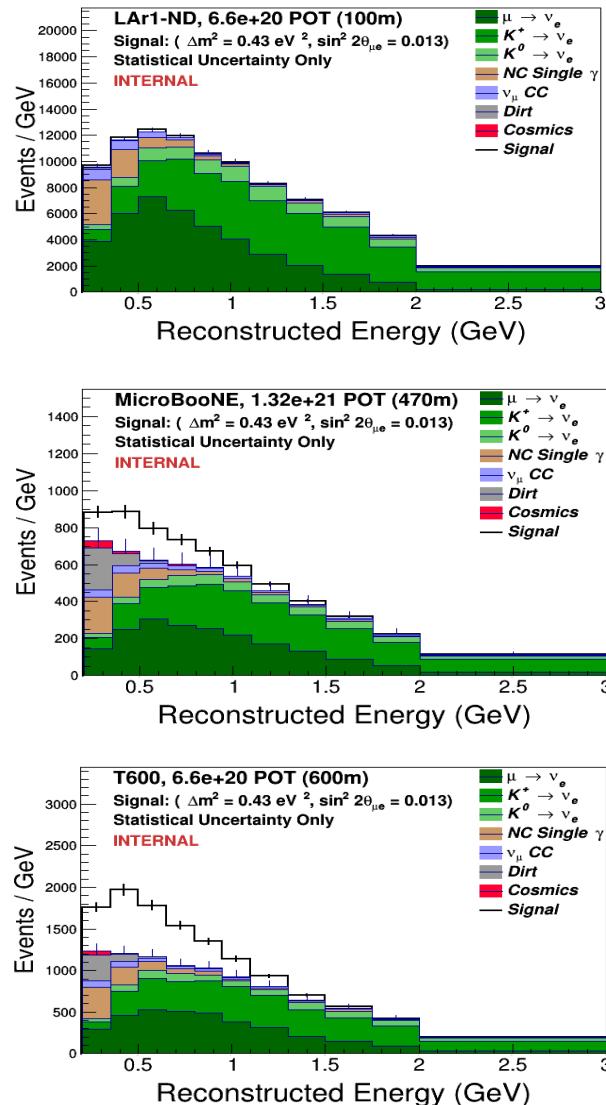
A Proposal for a Three Detector  
Short-Baseline Neutrino Oscillation Program  
in the Fermilab Booster Neutrino Beam

- The SBN program will consist of three LAr-TPC detectors:
  - **ICARUS-T600**: the only large-scale LAr-TPC in the world exposed to a neutrino beam
  - **MicroBooNE**: the largest LAr-TPC built in the US, starting operations in 2015
  - **LAr1-ND**: providing a new opportunity for development on the path to LBNF
- These three detectors and the international teams of physicists and engineers realizing them represent a significant scientific as well as R&D opportunity toward the future neutrino program.

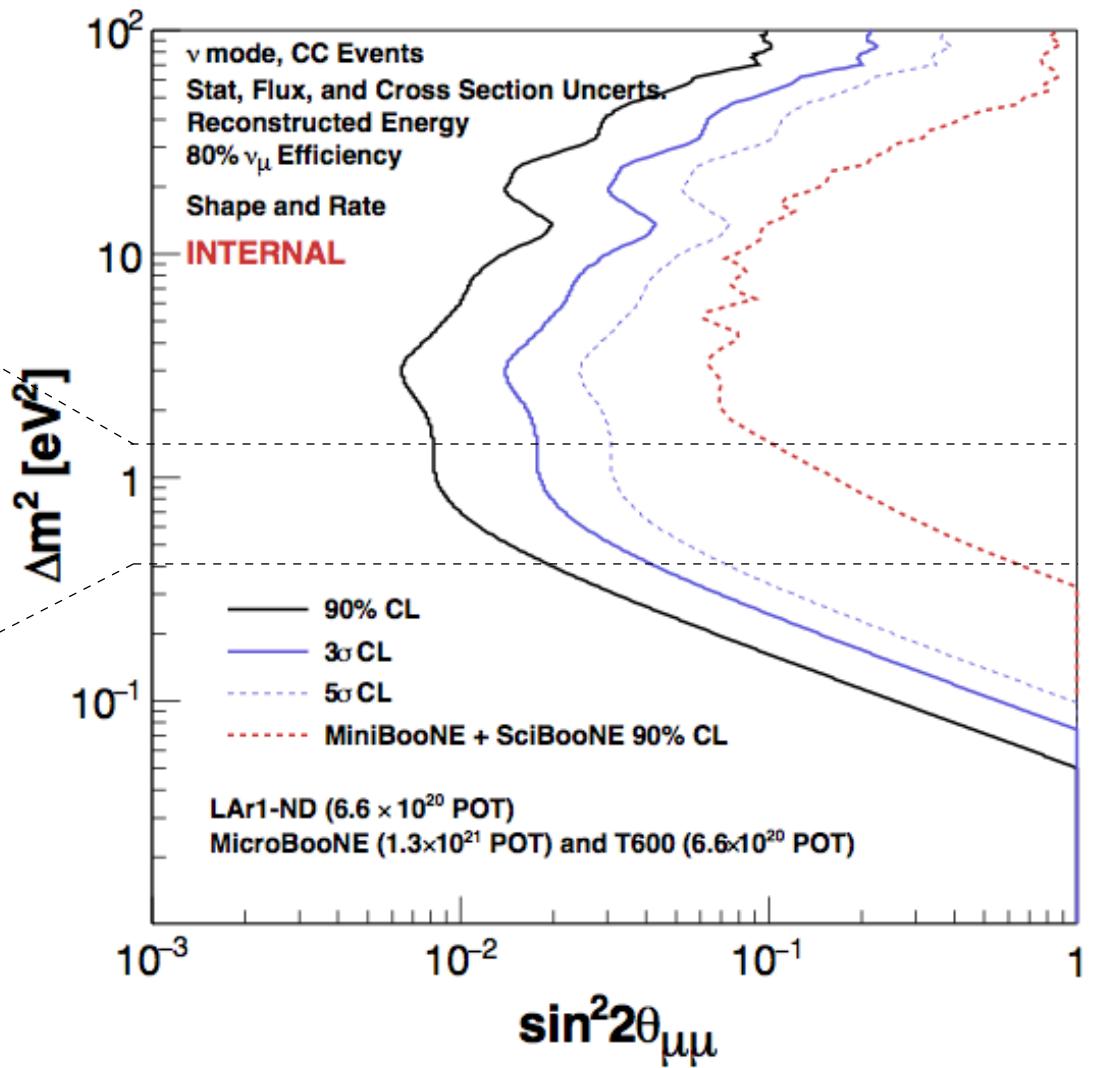
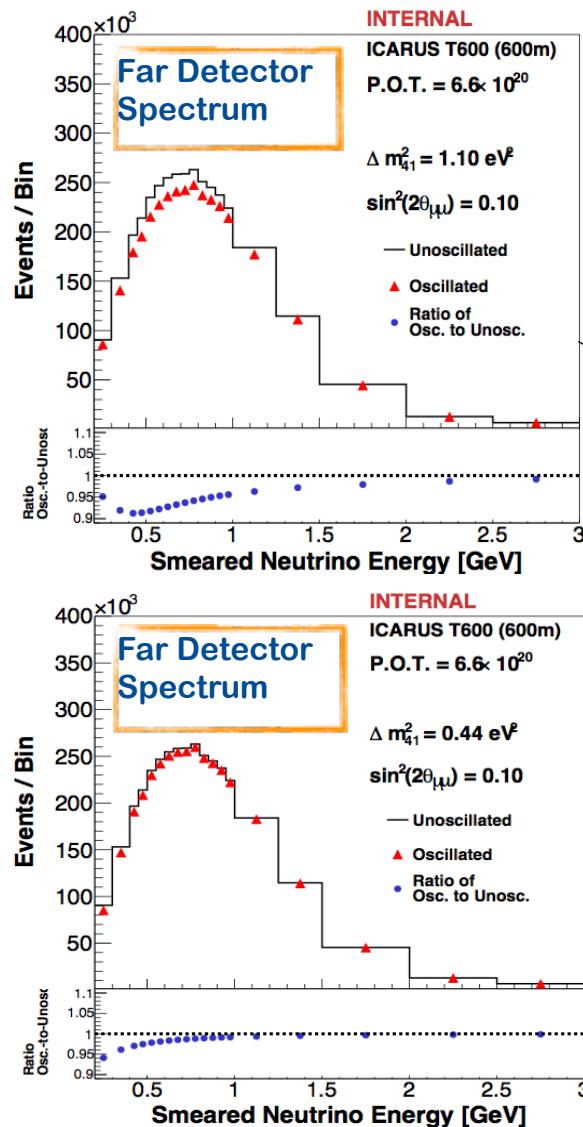
# SBN Program Layout



# SBN $\nu_e$ Appearance Sensitivity

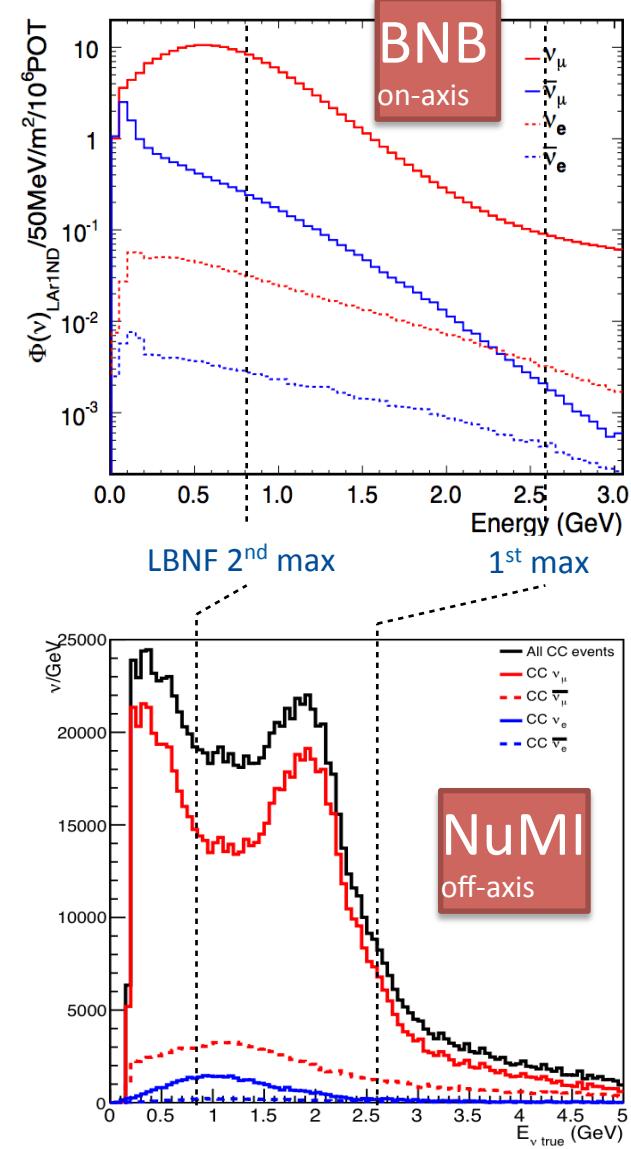


# SBN $\nu_\mu$ Disappearance Sensitivity



# Neutrino Interaction Physics and Event Reconstruction

- SBN detectors will collect large data sets from the BNB and the NuMI off-axis fluxes
  - ND: ~1.2M CC interactions per year (~7,000  $\nu_e$ )
  - Large complementary samples in MicroBooNE and T600
  - T600: ~100k NuMI off-axis events per year
- Precision measurements of  $\nu$ -Ar cross sections are an important component in reaching systematics at level of 1% in LBNF
- Large data sets will require that event reconstruction and analysis become fully automated
  - Precision testing of event reconstruction and identification techniques possible with large SBN data sets
  - This development for SBN physics will have direct impact for LBN in the future



# MicroBooNE



- The first phase of the next generation SBN Program begins this year with MicroBooNE coming online soon!
- Physics
  - Address MiniBooNE low energy excess
  - Measure  $\nu$ -Ar cross sections
- R&D
  - Argon fill without evacuation
  - Cold front-end electronics
  - Long drift (2.5m)
  - Near surface operation
  - Automated reconstruction
- Talk by Jyoti Joshi in Thursday afternoon breakout session

# ICARUS-T600

- Successful operation at Gran Sasso in CNGS beam
  - Achieved electron lifetime >15ms
  - Physics program including limits on sterile neutrinos
- ICARUS-WA104 collaboration: refurbish at CERN w/new cryostats and electronics, upgraded light detection
  - ✓ Move from Gran Sasso to CERN Dec 2014
  - ✓ Refurbishing starting
  - Schedule: TPC delivered to FNAL as soon as the building is available, currently foreseen as early 2017
- For surface operation need improved cosmic rejection:
  - Light detection, external tagger system
- Talk by Angela Fava in Thursday afternoon breakout session

Ready to leave LNGS

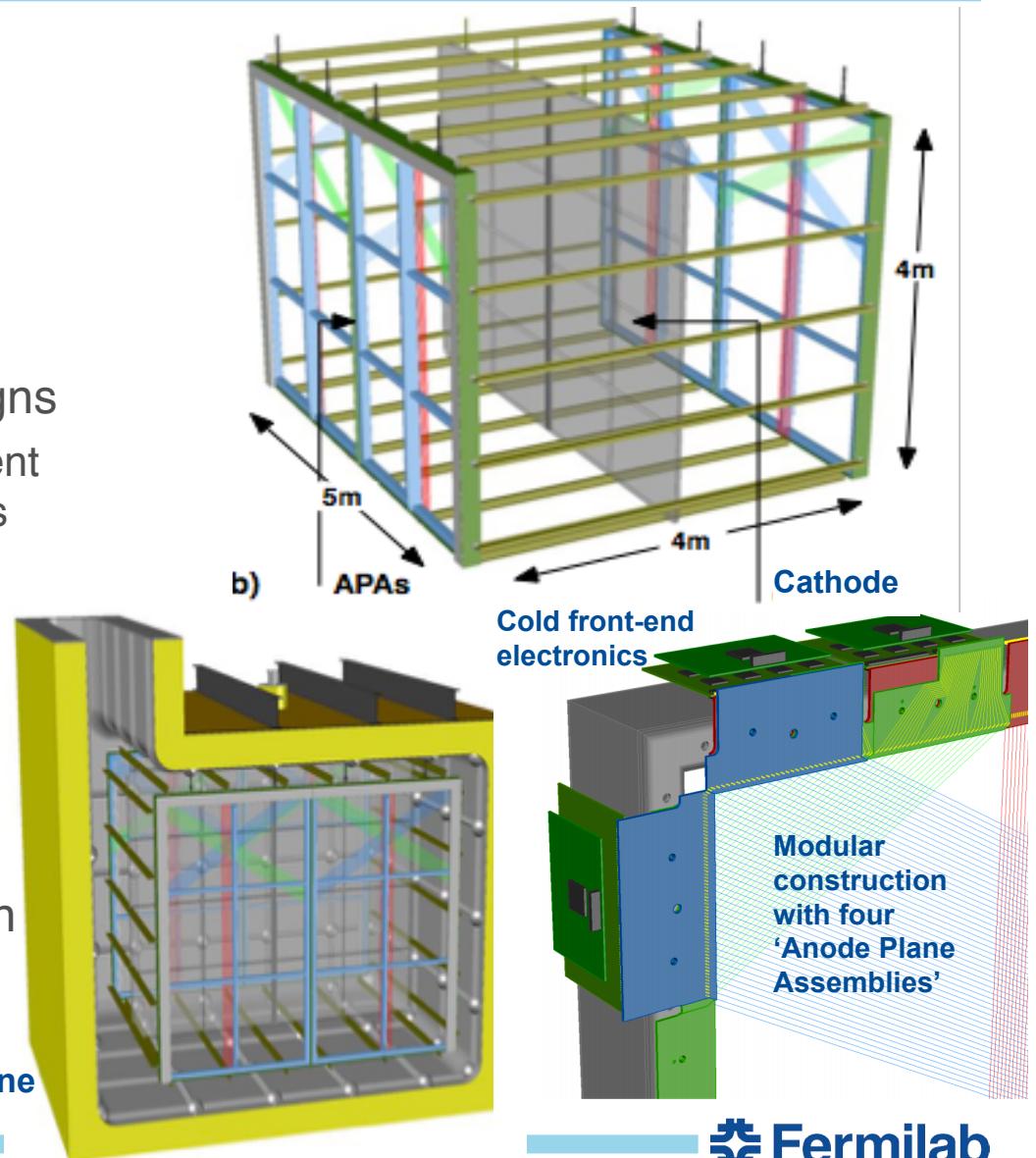


First T300 in Cleanroom at CERN



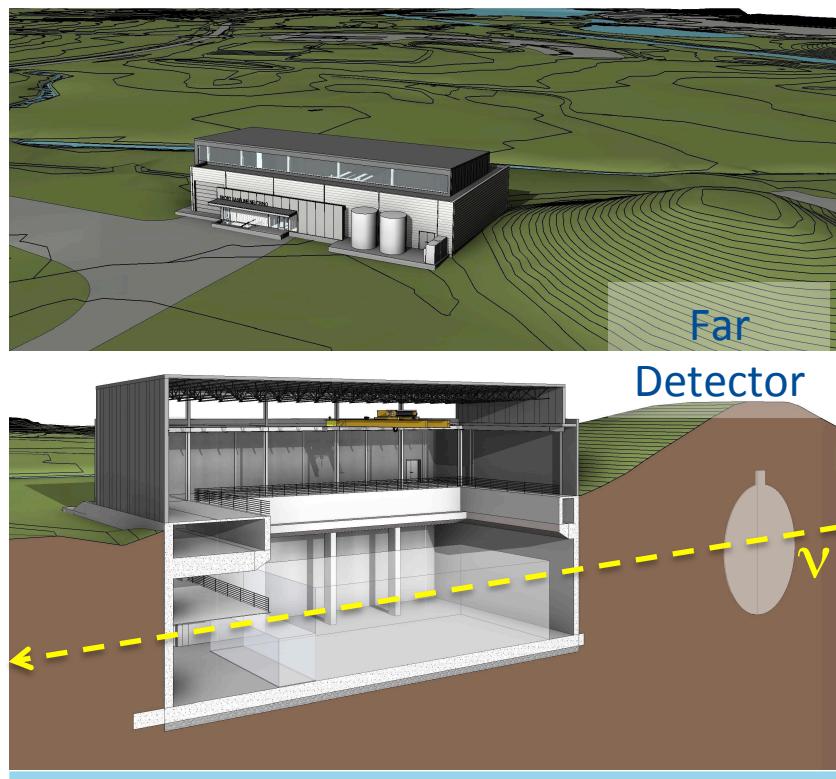
# LAr1-ND

- A new detector, building on experience from ICARUS, MicroBooNE, 35ton, and based on current LBNE designs
- Provides an opportunity for prototyping baseline designs or developing alternative system designs
  - For example, LAr1-ND is an excellent test-bed for light collection concepts being developed for LBNF physics
- LAr1-ND approved at FNAL as T-1053 in summer 2014, now developing technical design, pursuing needed R&D
- Talk by Bo Yu in Thursday afternoon breakout session

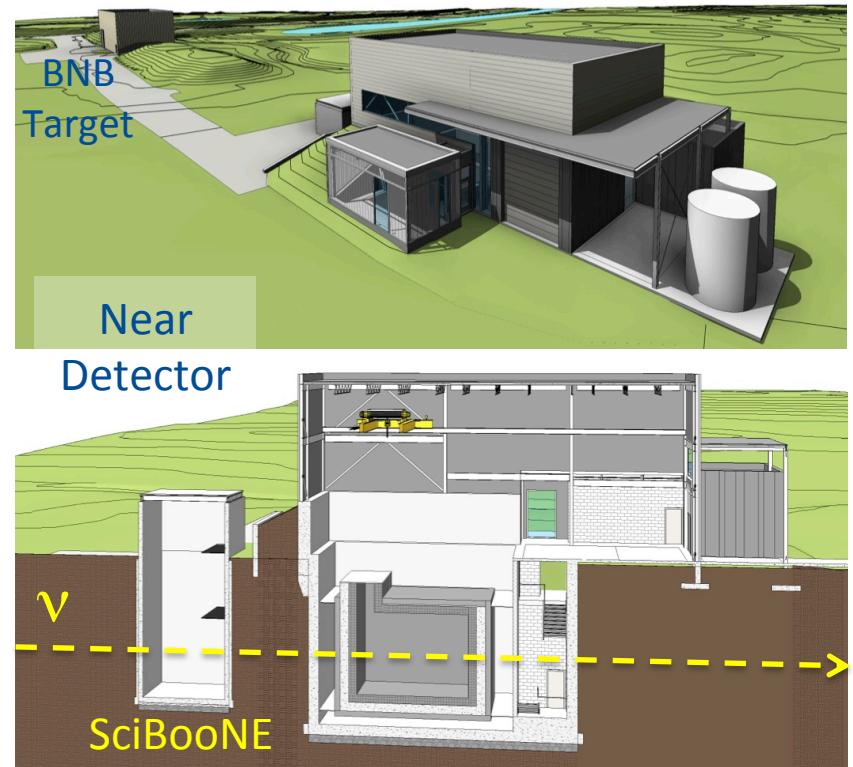


# New Detector Buildings

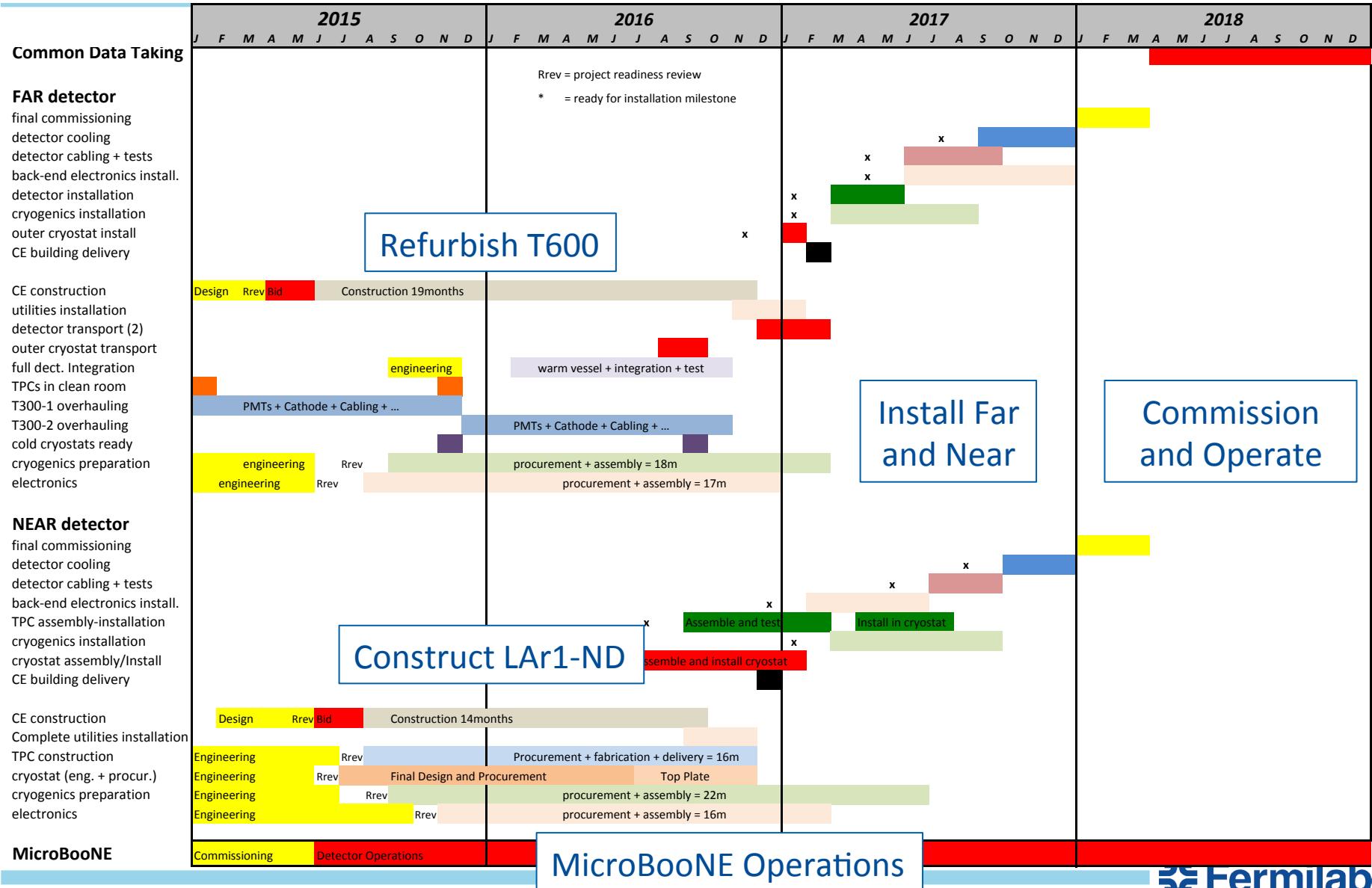
- Final designs in progress
- Include support for 3m concrete overburden inside each building
  - Mitigate cosmogenic backgrounds for near surface operation



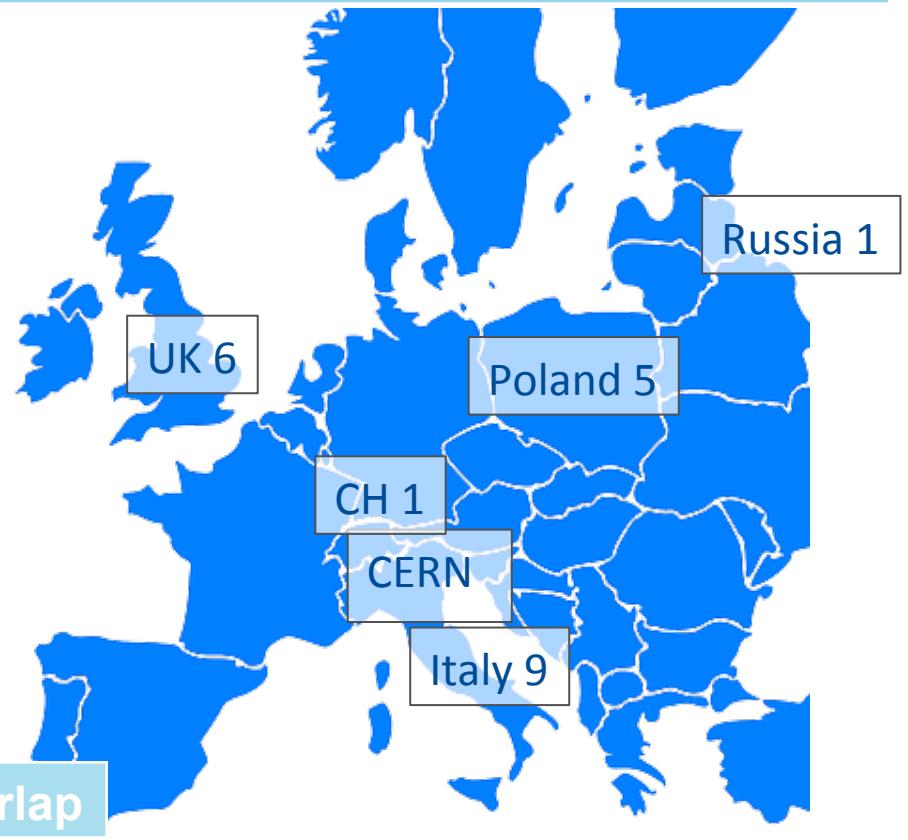
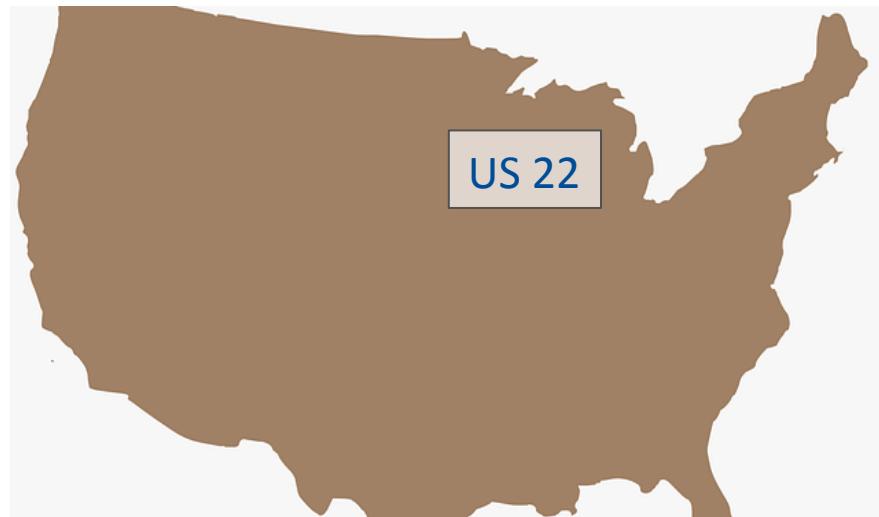
	Far	Near
Design Complete	Mar 2015	May 2015
Construction Start	May 2015	Aug 2015
Beneficial Occ.	Nov 2016	Sept 2016



# Program Schedule



# SBN Institutions and Authors



Collaboration	Authors	Overlap
ICARUS-WA104	57	
LAr1-ND	108	
MicroBooNE	118	
<b>All SBN (excl overlaps)</b>	<b>218</b>	

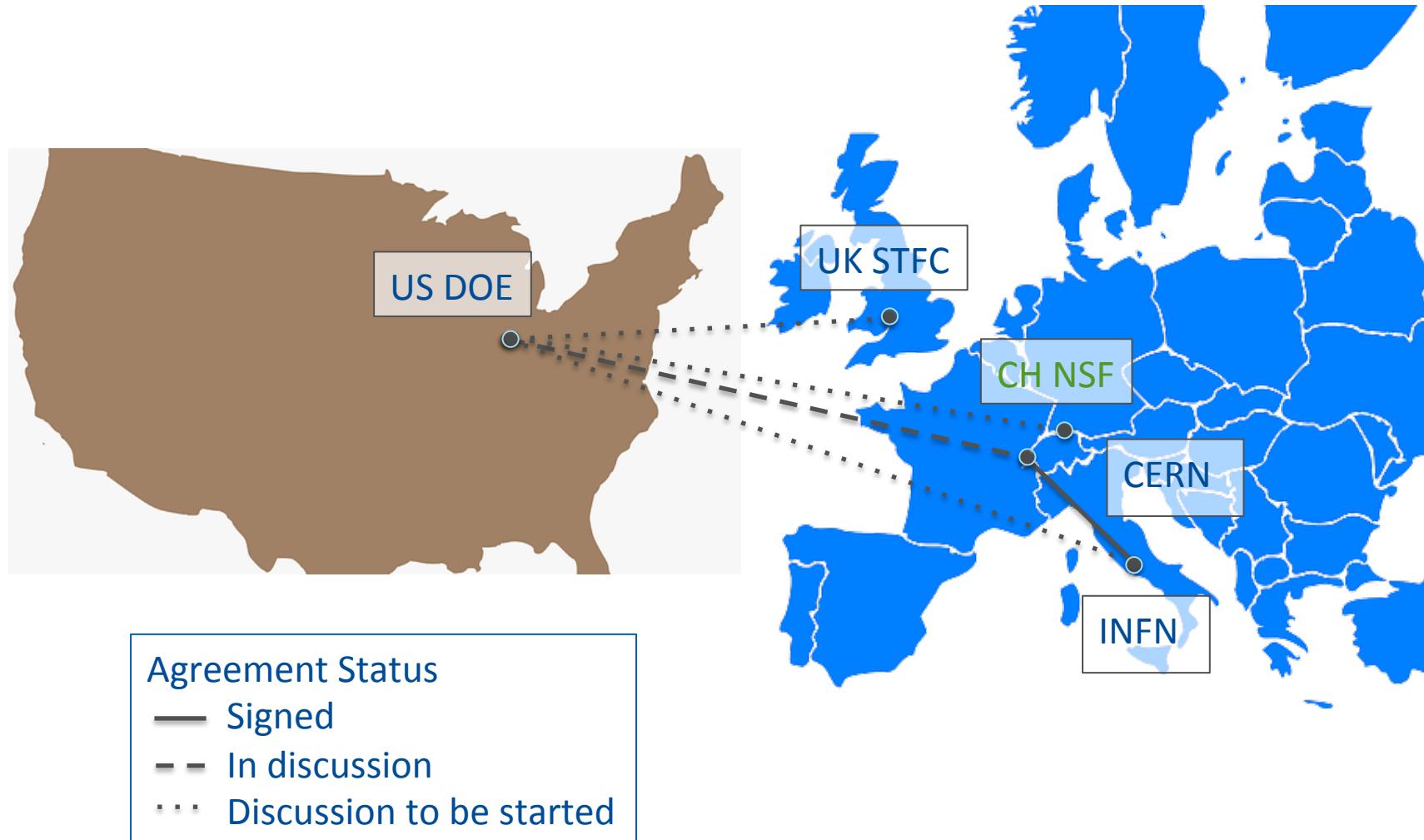
Institutions	SBN	SBN-ELBNF Overlap
US	22	20
Non-US	23	19

# Main SBN Funding Sources

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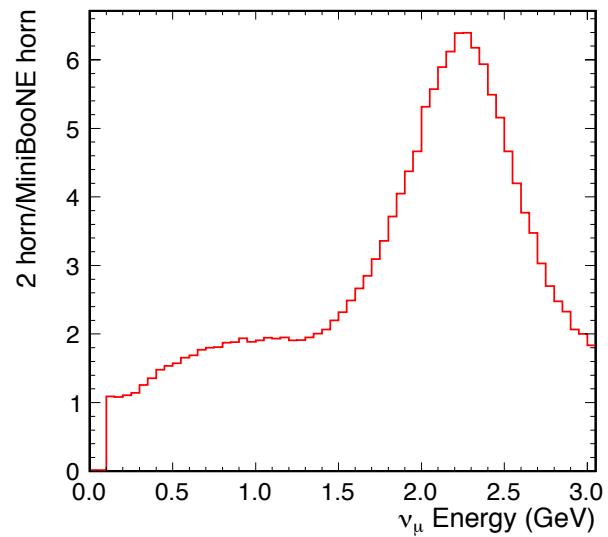
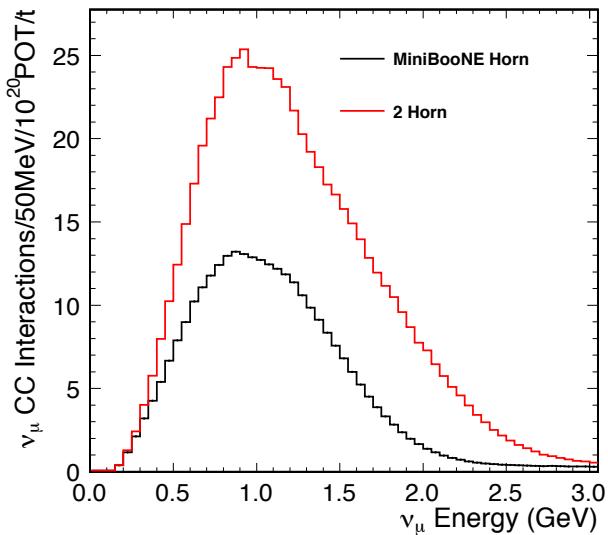
# Main SBN International Agreements



# BNB Improvements

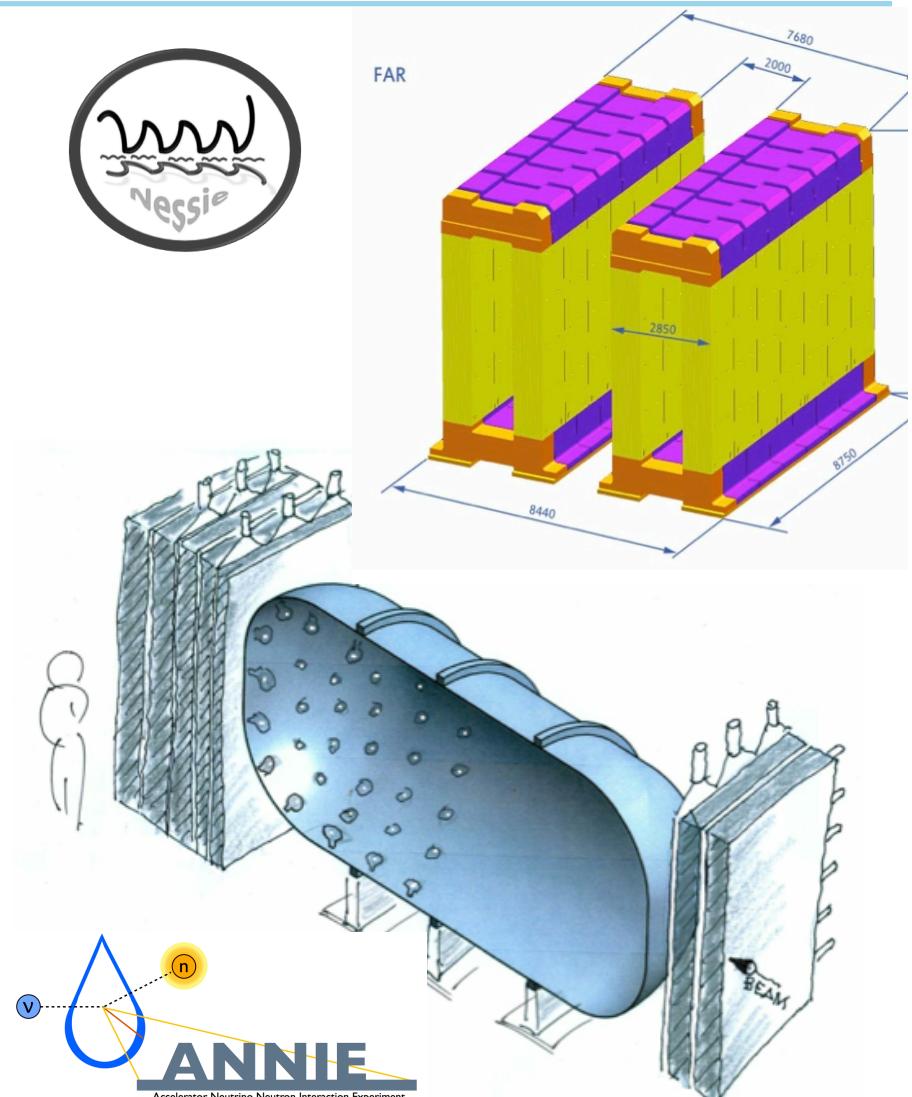
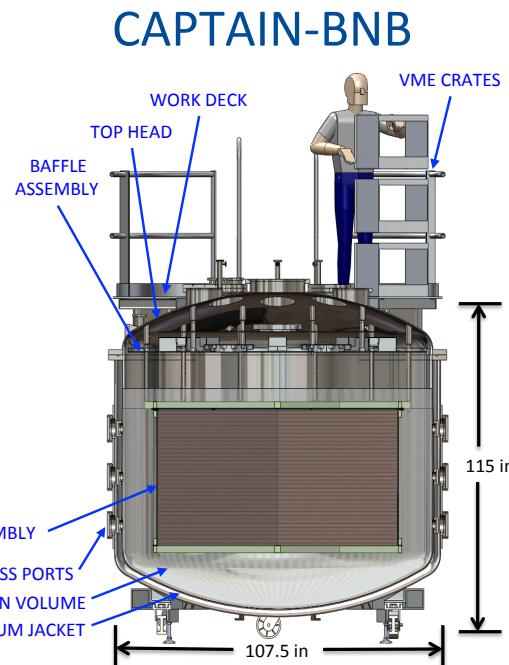
- Increased  $\nu$  statistics would further secure the program sensitivity
  - More protons on target
  - Higher  $\nu$  production efficiency
- BNB  $\nu$  energy distribution optimized for MiniBooNE Cherenkov detector
  - LAr-TPCs more tolerant of high energy tail
- Considering updated horn or two horn system
  - Provide up to factor of two more  $\nu$ /p.o.t.
  - Modest reconfiguration of proton beamline could provide space for 2<sup>nd</sup> horn
- Detailed plan with cost and schedule estimate by summer 2015
- See talk by Steve Brice in Thursday afternoon breakout

Example 2 Horn Flux



# Additional BNB Physics Opportunities

- In addition to the proposed SBN Program, continued BNB operation could support other experiments such as those presented to the Fermilab PAC in January 2015.



# Conclusions

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- The BNB is a unique facility providing an excellent base for a diverse neutrino physics program.
- The second generation of BNB physics is about to start with the operation of MicroBooNE.
- The three detector SBN program can make a definitive statement on the LSND and MiniBooNE anomalies with the potential for a ground breaking discovery in neutrino physics.
- This program brings together LAr-TPC detectors developed by leading teams of scientists and engineers from Europe and the US representing a tremendous scientific and R&D opportunity toward the future LBN program.
- We are moving forward aggressively to prepare the near and far detectors and required infrastructure for operation with beam by 2018.
  - SBN Program reviewed by Fermilab PAC – January 2015
  - Technical, cost and schedule reviews foreseen during 2015

# SBN Proposal Author List

## The ICARUS-WA104 Collaboration

M. Antonello<sup>16</sup>, B. Baibussinov<sup>31</sup>, V. Bellini<sup>5</sup>, P. Benetti<sup>32</sup>, S. Bertolucci<sup>6</sup>, H. Bilokon<sup>15</sup>, F. Boffelli<sup>32</sup>, M. Bonesini<sup>17</sup>, J. Bremer<sup>6</sup>, E. Calligarich<sup>32</sup>, S. Centro<sup>31</sup>, A.G. Cocco<sup>19</sup>, A. Dermenev<sup>20</sup>, A. Falcone<sup>32</sup>, C. Farnese<sup>31</sup>, A. Fava<sup>31</sup>, A. Ferrari<sup>6</sup>, D. Gibin<sup>31</sup>, S. Glinenko<sup>20</sup>, N. Golubev<sup>20</sup>, A. Guglielmi<sup>31</sup>, A. Ivashkin<sup>20</sup>, M. Kirsanov<sup>20</sup>, J. Kisiel<sup>38</sup>, U. Kose<sup>6</sup>, F. Mammoliti<sup>5</sup>, G. Mannocchi<sup>15</sup>, A. Menegolli<sup>32</sup>, G. Meng<sup>31</sup>, D. Mladenov<sup>6</sup>, C. Montanari<sup>32</sup>, M. Nessi<sup>6</sup>, M. Nicoletto<sup>31</sup>, F. Noto<sup>6</sup>, P. Picchi<sup>15</sup>, F. Pietropaolo<sup>31</sup>, P. Płoński<sup>42</sup>, R. Potenza<sup>5</sup>, A. Rappoldi<sup>32</sup>, G. L. Raselli<sup>32</sup>, M. Rossella<sup>32</sup>, C. Rubbia<sup>\*6,11,16</sup>, P. Sala<sup>18</sup>, A. Scaramelli<sup>18</sup>, J. Sobczyk<sup>44</sup>, M. Spanu<sup>32</sup>, D. Stefan<sup>18</sup>, R. Sulej<sup>43</sup>, C.M. Sutera<sup>5</sup>, M. Torti<sup>32</sup>, F. Tortorici<sup>5</sup>, F. Varanini<sup>31</sup>, S. Ventura<sup>31</sup>, C. Vignoli<sup>16</sup>, T. Wachala<sup>12</sup>, and A. Zani<sup>32</sup>

## The LAr1-ND Collaboration

C. Adams<sup>45</sup>, C. Andreopoulos<sup>23</sup>, A. Ankowski<sup>41</sup>, J. Asaadi<sup>40</sup>, L. Bagby<sup>10</sup>, B. Baller<sup>10</sup>, N. Barros<sup>33</sup>, M. Bass<sup>30</sup>, S. Bertolucci<sup>6</sup>, M. Bishai<sup>3</sup>, A. Bitadze<sup>25</sup>, J. Bremer<sup>6</sup>, L. Bugel<sup>26</sup>, L. Camilleri<sup>9</sup>, F. Cavanna<sup>a,10</sup>, H. Chen<sup>3</sup>, C. Chi<sup>9</sup>, E. Church<sup>10</sup>, D. Cianci<sup>7</sup>, G. Collin<sup>26</sup>, J.M. Conrad<sup>26</sup>, G. De Geronimo<sup>3</sup>, R. Dharmapalan<sup>1</sup>, Z. Djurcic<sup>1</sup>, A. Ereditato<sup>2</sup>, J. Esquivel<sup>40</sup>, J. Evans<sup>25</sup>, B.T. Fleming<sup>45</sup>, W.M. Foreman<sup>7</sup>, J. Freestone<sup>25</sup>, T. Gamble<sup>37</sup>, G. Garvey<sup>24</sup>, V. Genty<sup>9</sup>, D. Göldi<sup>2</sup>, H. Greenlee<sup>10</sup>, R. Guenette<sup>30</sup>, A. Hackenburg<sup>45</sup>, R. Hänni<sup>2</sup>, J. Ho<sup>7</sup>, J. Howell<sup>10</sup>, C. James<sup>10</sup>, C.M. Jen<sup>41</sup>, B.J.P. Jones<sup>26</sup>, L.M. Kalousis<sup>41</sup>, G. Karagiorgi<sup>25</sup>, W. Ketchum<sup>24</sup>, J. Klein<sup>33</sup>, J. Klinger<sup>37</sup>, U. Kose<sup>6</sup>, I. Kreslo<sup>2</sup>, V.A. Kudryavtsev<sup>37</sup>, D. Lissauer<sup>3</sup>, P. Livesly<sup>22</sup>, W.C. Louis<sup>24</sup>, M. Lu $\square$ thi<sup>2</sup>, C. Mariani<sup>41</sup>, K. Mavrokorditis<sup>23</sup>, N. McCauley<sup>23</sup>, N. McConkey<sup>37</sup>, I. Mercer<sup>22</sup>, T. Miao<sup>10</sup>, G.B. Mills<sup>24</sup>, D. Mladenov<sup>6</sup>, D. Montanari<sup>10</sup>, J. Moon<sup>26</sup>, Z. Moss<sup>26</sup>, S. Mufson<sup>14</sup>, M. Nessi<sup>6</sup>, B. Norris<sup>10</sup>, F. Noto<sup>6</sup>, J. Nowak<sup>22</sup>, S. Pal<sup>37</sup>, O. Palamara<sup>\*b,10</sup>, J. Pater<sup>25</sup>, Z. Pavlovic<sup>10</sup>, J. Perkin<sup>37</sup>, G. Pulliam<sup>40</sup>, X. Qian<sup>3</sup>, L. Qiuguang<sup>24</sup>, V. Radeka<sup>3</sup>, R. Rameika<sup>10</sup>, P.N. Ratoff<sup>22</sup>, M. Richardson<sup>37</sup>, C. Rudolf von Rohr<sup>2</sup>, D.W. Schmitz<sup>\*7</sup>, M.H. Shaevitz<sup>9</sup>, B. Sippach<sup>9</sup>, M. Soderberg<sup>40</sup>, S. Söldner-Rembold<sup>23</sup>, J. Spitz<sup>26</sup>, N. Spooner<sup>37</sup>, T. Strauss<sup>2</sup>, A.M. Szczec<sup>25,45</sup>, C.E. Taylor<sup>24</sup>, K. Terao<sup>9</sup>, M. Thiesse<sup>37</sup>, L. Thompson<sup>37</sup>, M. Thomson<sup>4</sup>, C. Thorn<sup>3</sup>, M. Toups<sup>26</sup>, C. Touramanis<sup>23</sup>, R.G. Van De Water<sup>24</sup>, M. Weber<sup>2</sup>, D. Whittington<sup>14</sup>, T. Wongjirad<sup>26</sup>, B. Yu<sup>3</sup>, G.P. Zeller<sup>10</sup>, and J. Zennamo<sup>7</sup>

## The MicroBooNE Collaboration

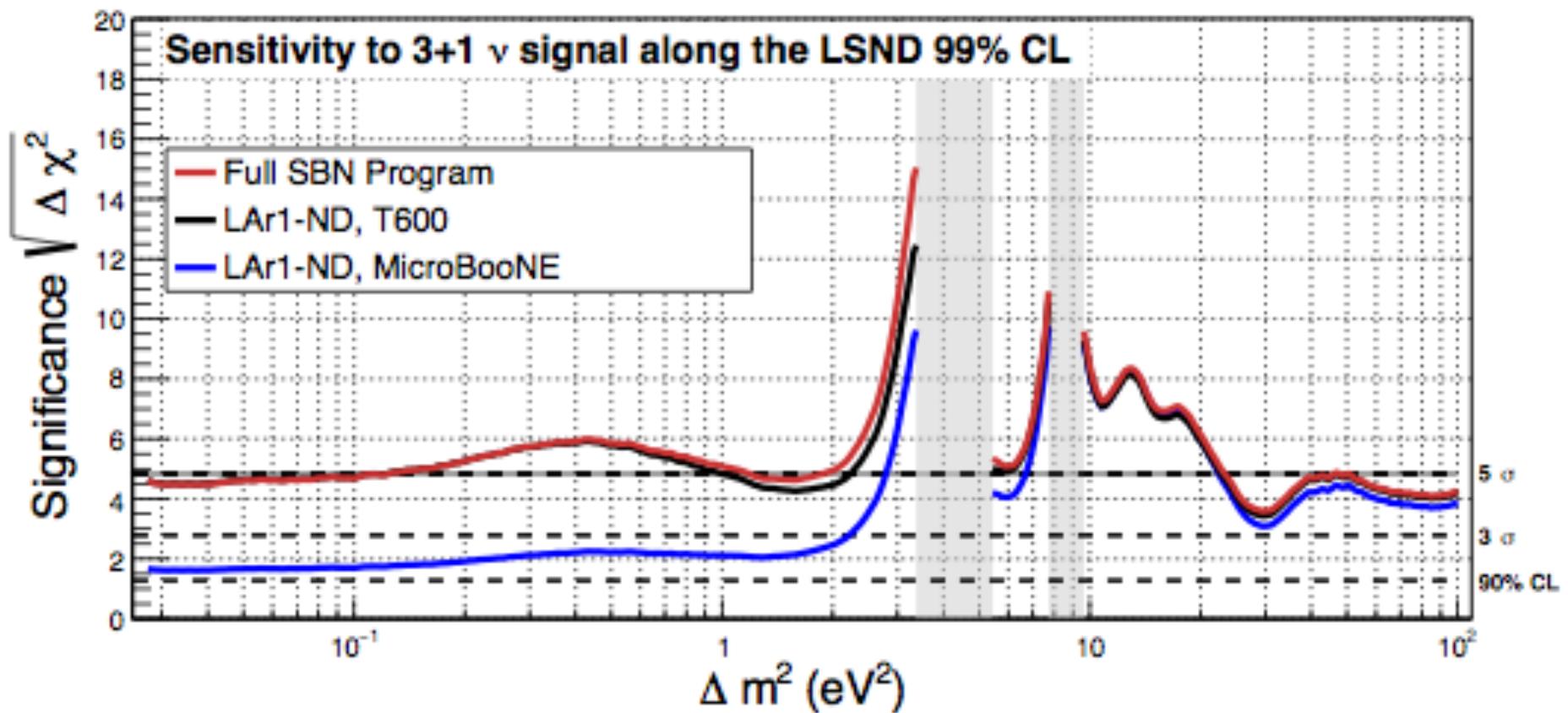
R. Acciarri<sup>10</sup>, C. Adams<sup>45</sup>, R. An<sup>13</sup>, A. Ankowski<sup>41</sup>, J. Asaadi<sup>40</sup>, L. Bagby<sup>10</sup>, B. Baller<sup>10</sup>, G. Barr<sup>30</sup>, M. Bass<sup>30</sup>, M. Bishai<sup>3</sup>, A. Blake<sup>4</sup>, T. Bolton<sup>21</sup>, C. Bromberg<sup>27</sup>, L. Bugel<sup>26</sup>, L. Camilleri<sup>9</sup>, D. Caratelli<sup>9</sup>, B. Carls<sup>10</sup>, F. Cavanna<sup>a,10</sup>, H. Chen<sup>3</sup>, E. Church<sup>10</sup>, G.H. Collin<sup>26</sup>, J.M. Conrad<sup>26</sup>, M. Convery<sup>39</sup>, S. Dytmar<sup>34</sup>, B. Eberly<sup>39</sup>, A. Ereditato<sup>2</sup>, J. Esquivel<sup>40</sup>, B.T. Fleming<sup>\*45</sup>, W.M. Foreman<sup>7</sup>, V. Genty<sup>9</sup>, D. Göldi<sup>2</sup>, S. Gollapinni<sup>21</sup>, M. Graham<sup>39</sup>, E. Gramellini<sup>45</sup>, H. Greenlee<sup>10</sup>, R. Grossos<sup>8</sup>, R. Guenette<sup>30</sup>, A. Hackenburg<sup>45</sup>, O. Hen<sup>26</sup>, J. Hewes<sup>25</sup>, J. Ho<sup>7</sup>, G. Horton-Smith<sup>21</sup>, C. James<sup>10</sup>, C.M. Jen<sup>41</sup>, R.A. Johnson<sup>8</sup>, B.J.P. Jones<sup>26</sup>, J. Joshi<sup>3</sup>, H. Jostlein<sup>10</sup>, D. Kaleko<sup>9</sup>, L. Kalousis<sup>41</sup>, G. Karagiorgi<sup>25</sup>, W. Ketchum<sup>24</sup>, B. Kirby<sup>3</sup>, M. Kirby<sup>10</sup>, T. Kobilarcik<sup>10</sup>, I. Kreslo<sup>2</sup>, Y. Li<sup>3</sup>, B. Littlejohn<sup>13</sup>, D. Lissauer<sup>3</sup>, S. Lockwitz<sup>10</sup>, W.C. Louis<sup>24</sup>, M. Lu $\square$ thi<sup>2</sup>, B. Lundberg<sup>10</sup>, A. Marchionni<sup>10</sup>, C. Mariani<sup>41</sup>, J. Marshall<sup>1</sup>, K. McDonald<sup>35</sup>, V. Meddagae<sup>21</sup>, T. Miceli<sup>28</sup>, G.B. Mills<sup>24</sup>, J. Moon<sup>26</sup>, M. Mooney<sup>3</sup>, M.H. Moulai<sup>26</sup>, R. Murrells<sup>25</sup>, D. Naples<sup>34</sup>, P. Nienaber<sup>36</sup>, O. Palamara<sup>b,10</sup>, V. Paolone<sup>34</sup>, V. Papavassiliou<sup>28</sup>, S. Pate<sup>28</sup>, Z. Pavlovic<sup>10</sup>, S. Pordes<sup>10</sup>, G. Pulliam<sup>40</sup>, X. Qian<sup>3</sup>, J.L. Raaf<sup>10</sup>, V. Radeka<sup>3</sup>, R. Rameika<sup>10</sup>, B. Rebel<sup>10</sup>, L. Rochester<sup>39</sup>, C. Rudolf von Rohr<sup>2</sup>, B. Russell<sup>45</sup>, D.W. Schmitz<sup>10</sup>, A. Schukraft<sup>10</sup>, W. Seligman<sup>9</sup>, M. Shaevitz<sup>9</sup>, M. Soderberg<sup>40</sup>, J. Spitz<sup>26</sup>, J. St. John<sup>8</sup>, T. Strauss<sup>2</sup>, A.M. Szczec<sup>25,45</sup>, N. Tagg<sup>29</sup>, K. Terao<sup>9</sup>, M. Thomson<sup>4</sup>, C. Thorn<sup>3</sup>, M. Toups<sup>26</sup>, Y. Tsai<sup>39</sup>, T. Usher<sup>39</sup>, R. Van de Water<sup>24</sup>, M. Weber<sup>2</sup>, S. Wolbers<sup>10</sup>, T. Wongjirad<sup>26</sup>, K. Woodruff<sup>28</sup>, M. Xu<sup>13</sup>, T. Yang<sup>10</sup>, B. Yu<sup>3</sup>, G.P. Zeller<sup>\*10</sup>, J. Zennamo<sup>7</sup>, and C. Zhang<sup>3</sup>

## Additional Fermilab Contributors

W. Badgett<sup>10</sup>, K. Biery<sup>10</sup>, S. Brice<sup>10</sup>, S. Dixon<sup>10</sup>, M. Geynisman<sup>10</sup>, C. Moore<sup>10</sup>, E. Snider<sup>10</sup>, and P. Wilson<sup>10</sup>

- Collaboration spokespeople
- Fermilab SBN Program Coordinator

# Impact of Three Detector System



# Comparison to MiniBooNE $\nu$ Mode

